Midlatitude Aerosol-Cloud-Radiation Feedbacks in Marine Boundary Layer Clouds

Yefim L. Kogan
Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma
phone: (405)326-8266; fax: (405) 325-3098; email: ykogan@ou.edu

Grant #: N00014-08-10681

LONG-TERM GOALS

The development and improvement of cloud microphysical parameterizations for use in cloud and numerical weather prediction models

OBJECTIVES

Conduct detailed studies of marine stratocumulus cloud microphysical processes in order to achieve a better understanding of interactions between microphysical, radiative and boundary layer thermodynamical processes and to improve their formulation in numerical weather prediction models. Develop parameterizations of individual cloud physics processes for use in numerical weather prediction models.

APPROACH

The research is based on the CIMMS high-resolution large eddy simulation (LES) model of marine boundary layer stratocumulus clouds with explicit formulation of aerosol and drop size-resolving microphysics. The LES simulations, as well as observations from field projects are used to study drizzle formation in marine stratocumulus. This year we also started analyzing data from the RICO field project that will be used as a basis for cloud physics parameterizations applicable for shallow convective cumuliform clouds.

WORK COMPLETED

The following tasks have been completed this year:

1. The parameterization of drop size distributions in drizzling stratiform clouds.
2. The LES simulations of low layer stratiform clouds over continental areas.
3. The enhancement of analysis tools for LES data processing needed for development and improvement of cloud microphysical parameterizations in cumulus convective clouds

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Midlatitude Aerosol-Cloud-Radiation Feedbacks In Marine Boundary Layer Clouds**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Oklahoma,Cooperative Institute for Mesoscale Meteorological Studies,Norman,OK,73019**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Conduct detailed studies of marine stratocumulus cloud microphysical processes in order to achieve a better understanding of interactions between microphysical, radiative and boundary layer thermodynamical processes and to improve their formulation in numerical weather prediction models. Develop parameterizations of individual cloud physics processes for use in numerical weather prediction models

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

RESULTS

1. The parameterization of drop size distributions in drizzling stratiform clouds

The development of cloud microphysics parameterizations and cloud microphysical retrievals rely heavily on the knowledge of the shape of drop size distributions (DSDs). Many investigations assume that DSDs in the whole, or parts of the drop size range, may be approximated by known analytical functions. The most frequently employed approximations are gamma, lognormal, Khrgian-Mazin, and Marshall-Palmer type functions. At present, little is known about the accuracy of each of these approximations, especially their ability to successfully simulate the higher moments of the DSD. We have evaluated the applicability and accuracy of DSD approximations using a combination of lognormal and gamma-type functions for stratocumulus and shallow convective clouds. The DSDs were generated using the new version of the CIMMS LES explicit microphysics model (SAMEX) in simulations of cases observed during the ASTEX and DYCOMS-II field projects. Special emphasis in the analysis was placed on the fidelity of representing the higher moments of the drop spectra, such as precipitation flux and radar reflectivity. We found that approximating drop spectra in drizzling stratocumulus by Gamma-type distributions proves to be much more accurate than approximation by the lognormal distribution (see Fig. 1). In drizzling stratocumulus the two mode approximations provided better accuracy than the one-mode approximations. We also concluded that in numerical models which use two-moment microphysical parameterization schemes, the six parameters defining the two-mode Gamma distribution can be expressed through the four predictive microphysical variables describing concentrations and mixing ratios of cloud and rain drops. The latter approach requires parameterization of the drizzle mode dispersion which was developed as part of this project. The results of this research were published in the Journal of Atmospheric Sciences article.

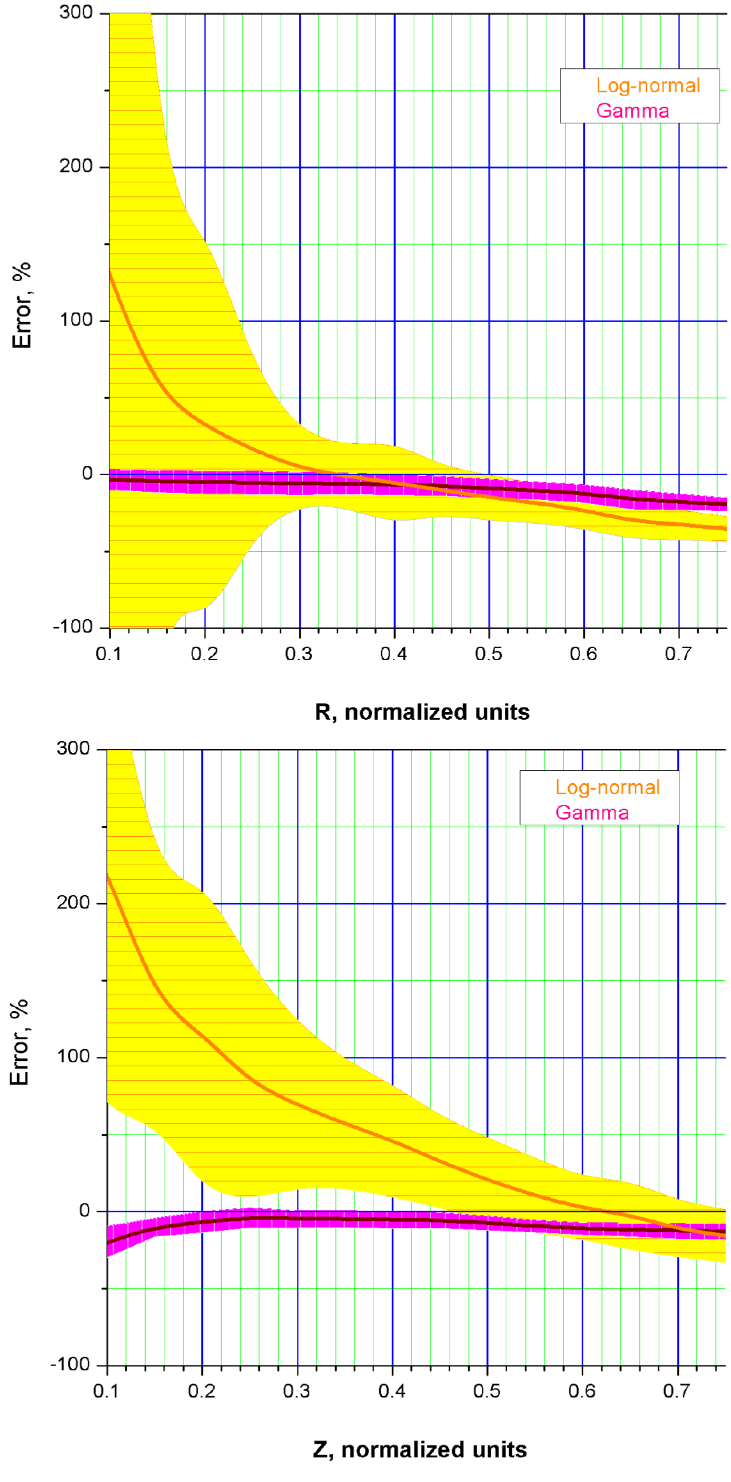

Figure 1. Errors of approximation of normalized rain rates R and radar reflectivity Z by bimodal analytical fits in the HD case. Radar reflectivity range (-35, +5) dBZ was linearly transformed into (0, 1) interval. [graph: for marine stratocumulus clouds gamma type analytical approximation of drop size distributions is much more accurate than lognormal]

2. LES simulations of low layer stratiform clouds dependence on large scale forcing

Long term forecasts of marine stratiform clouds require considerations of large mesoscale cloud systems which cover both oceanic and continental areas. While most of the previous studies focused on marine boundary layer clouds, only very few explicitly addressed low layer clouds over the continent. Nevertheless, the low-altitude continental boundary layer stratus clouds constitute a significant effect on the energetics of mesoscale cloud systems which is important to understand for correct representation of these clouds in regional weather prediction models. Our study aimed at investigation of the capabilities of the LES modeling approach to realistically simulate the continental boundary layer clouds. The study has capitalized on the suite of observational instruments centered at the Atmospheric Radiation Measurement Program (ARM) Climate Research Facility (ACRF) Southern Great Plains site in northern Oklahoma that includes a millimeter-wave Doppler cloud radar (MMCR) in addition to the ground-based passive (shortwave, longwave, and microwave) radiometers, as well as active remote sensors (ceilometers and micro pulse lidar). The extensive high spatial and temporal observations are capable to capture the turbulent flow structures and are referred to as "large eddy observations" (LEOs) (Kollias and Albrecht, 2000, *J. Atmos.Sci.*, vol. **57**).

In order to identify the influence of large scale forcing on the structure and evolution of continental stratocumulus clouds, we complement LES simulations with the LEO analysis. We found that LES simulation are quite sensitive to changes in forcing, with even modest changes in the large-scale forcings, particularly the large-scale temperature and moisture advection, producing significant differences in liquid water path (LWP) (Fig. 2). This implies an important difference from marine stratocumulus, where the evolution of the boundary layer is driven mostly by cloud top inversion parameters. The result is of important significance for regional forecast models that resolve horizontal advection much more accurately than cloud top entrainment. A two-part paper describing study results from both LEO analysis and LES model experiments will be submitted to Monthly Weather Review in the coming months.

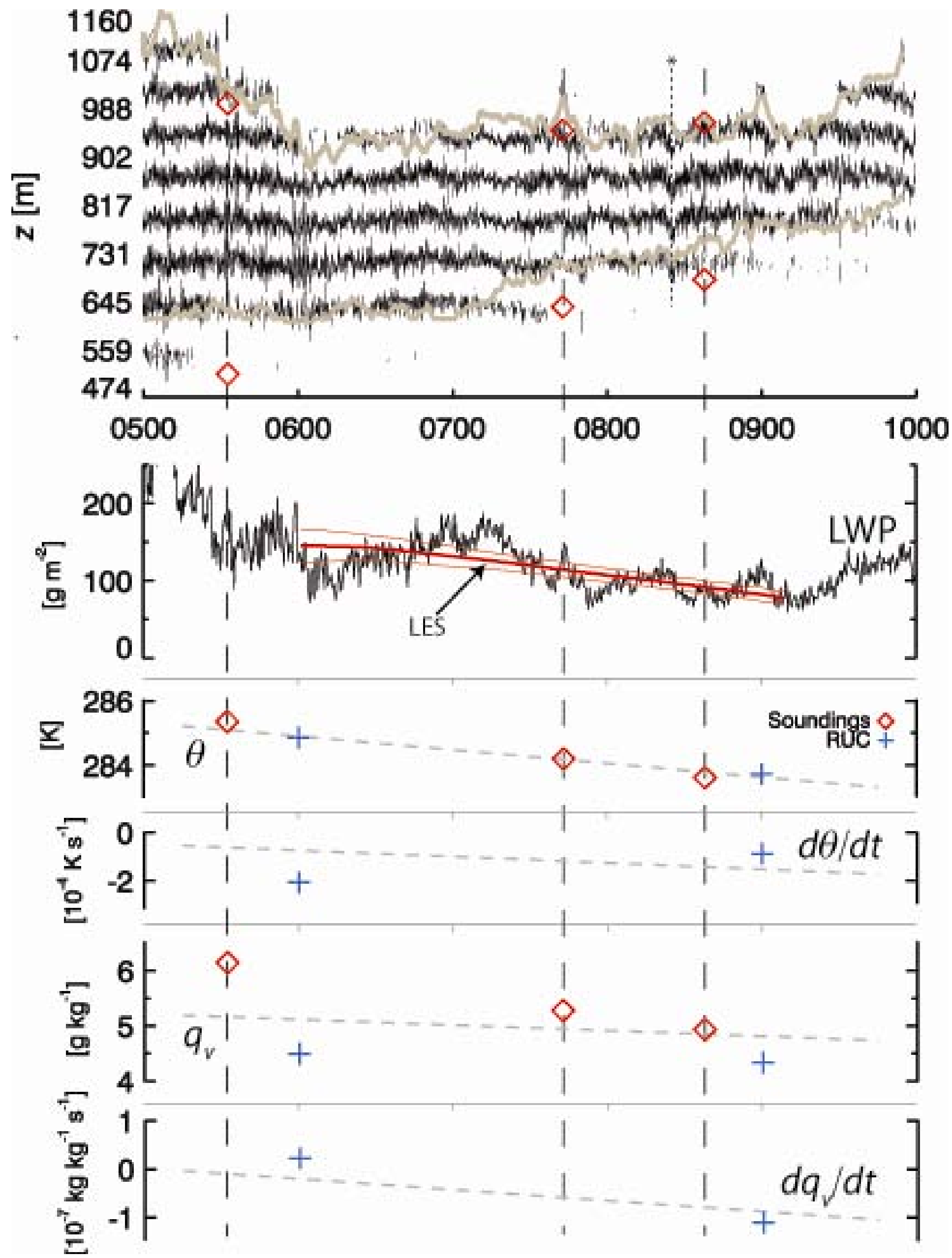

Figure 2. The cloud parameters obtained from large eddy observations and LES model simulations: Top panel shows time series of radial velocity at various gates in the cloud as observed by W-band cloud radar. The velocity difference between plotted gates is 2 m s^{-1}. The gray lines indicate cloud base and top. The diamonds in the top panel represent cloud top and cloud base estimates. The time series below the radar panel indicates liquid water path (LWP) as estimated from microwave radiometer overlaid with data from LES simulations. Thick red line corresponds to the mean, while the two outer lines correspond to an interval of ±2σ. Potential temperature and water vapor mixing ratio from three soundings are plotted along with the θ and q_v tendencies from the RUC at 0600 and 0900 UTC. [graph: LES simulations can realistically represent the effect of synoptic forcings on continental clouds overall parameters]

3. The development and improvement of cloud microphysical parameterizations in cumulus convective clouds for use in numerical weather prediction models

The work on the development of a comprehensive bulk microphysical parameterization for cumulus convective clouds has continued. This research uses explicit (drop spectrum resolving) microphysical model which serves as a data source and as a benchmark for comparison of the developed parameterization. Our previous research emphasized that the development of an accurate cloud physics parameterization requires the use of the dynamically balanced cloud drop spectra dataset. The best tool to create such dataset is an LES model with explicit microphysics, since it is able to provide a full range of drop spectra generated by realistically represented dynamics and turbulence. Several case studies using data from the Rain in Cumulus over the Ocean (RICO) field project have been conducted and results analyzed by comparison with available observational studies. For data analysis and model verification we have developed several complex analysis tools which allow us automatically detect cloud cells and define their geometrical, thermodynamical and microphysical parameters. This task has been accomplished in collaboration with Prof. S. Gutman from the Mathematics Department at the University of Oklahoma. The new software tools will allow selective data sampling for cloud cells with varying intensity. The analyzed datasets have been utilized to develop parameterizations for main conversion rates, such as autoconversion/accretion of cloud water into/by drizzle, as well as rain drop concentration and mixing ratio fall velocities. The testing of the developed parameterization will continue in the framework of the bulk version of SAMEX the development of which will be the major focus of our efforts during the next year.

IMPACT

The improved parameterization of the physical processes in marine stratocumulus clouds will lead to more accurate numerical weather predictions for Navy operations.

TRANSITIONS

Our results have been published in four refereed scientific journals, four conference proceedings, and reported at five scientific meetings.

PUBLICATIONS

Kogan, Y.L., Z. N. Kogan, and D. B. Mechem, 2009: Fidelity of Analytic Drop Size Distributions in Drizzling Stratiform Clouds Based on Large-Eddy Simulations, *J. Atmos. Sci*, **66**, 2335–2348.

Mechem, D. B., Y. L. Kogan, D. Shultz, 2009: Study of post-frontal continental stratus: Part I. Large Eddy Observations. To be submitted to *Monthly Weather Review*

Mechem, D. B., Y. L. Kogan, D. Shultz, 2009: Study of post-frontal continental stratus: Part II. Large Eddy Simulations. To be submitted to *Monthly Weather Review*

Mechem, D. B., Y. L. Kogan, M. Ovtchinnikov, A. B. Davis, K. F. Evans, and R. G. Ellingson, 2008: Multi-dimensional longwave forcing of boundary layer cloud systems. *J. Atmos. Sci.*, 65, 3963–3977.

Mechem, D. B. and Y.L. Kogan, 2008: A bulk parameterization of Giant CCN, *J. Atmos. Sci*, 65, 2458-2466.

Lan Yi, Kogan, Y. L., and D. B. Mechem, 2008: An idealized modeling study of the effect of continental air mass aerosol parameters on marine stratocumulus, *J. Atmos. Res*, 88, 157-167.

Mechem, D. B. and Y. L. Kogan, 2008: Scalings for precipitation and coalescence scavenging obtained from simulations of trade cumulus. *15th Inter. Conf. on Clouds and Precipitation*, Cancun, Mexico.

Mechem, D.B. and Y. L. Kogan, 2008: Structure and persistence of post-frontal stratus in numerical models, *Proc. of the Eighteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, ARM-CONF-2008, Norfolk, VA.

Kogan, Z. N. and Y. L. Kogan, 2008: Using cloud radars to verify two-moment bulk cloud parameterizations, *Proc. of the Eighteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, ARM-CONF-2008, Norfolk, VA.

Kogan, Y. L., Z. N. Kogan, and D. B. Mechem, 2008: Using Doppler radars for remote sensing of cloud water and precipitation in low layer clouds, 17th Conference on Applied Climatology, Whistler, BC, Canada

Fox-Rabinovitz, M., V. Krasnopolsky, P. Rasch, Y. Kogan, A. Belochitski, 2009: Development of Ensemble Neural Network Convection Parameterizations for Climate Models Using ARM Data. *Proc. of the 19th Atmospheric Radiation Measurement (ARM) Science Team Meeting*, Louisville, KY.